WHITECAP COVERAGE FROM AERIAL PHOTOGRAPHY

by

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INTRODUCTION

This paper describes a portion of the Visibility Laboratory program devoted to determining the feasibility of deriving sea surface wind speeds by remotely sensing ocean surface radiances in the non-glitter regions. With a knowledge of the duration and geographical extent of the wind field, information about the conventional sea state may be derived.

The work has been supported by the Spacecraft Oceanography Project of the Naval Oceanographic Office. The documented aerial photography used was obtained on the Earth Resources Aircraft Project Missions 88, 113, and 119 conducted during 1969 and 1970.

The use of optical techniques for determining sea state has obvious limitations. For example, such means can be used only in daylight and only when a clear path of sight is available between the sensor and the surface. However, sensors and vehicles capable of providing the data needed for such techniques are planned for the near future; therefore, a secondary or backup capability can be provided with little added effort.

In addition to the primary objective of the work noted above, the information currently being sought regarding white water coverage is also of direct interest to those working with passive microwave systems, the study of energy transfer between winds and ocean currents, the aerial estimation of wind speeds, and many others.

DESCRIPTION OF REMOTE SENSING TECHNIQUE

The ocean surface winds and the resulting sea state usually do not need to be known with high spatial resolution. For most purposes, resolution sizes measured in kilometers are sufficient. Low resolution television or scanning radiometer systems can easily supply the needed input data if the radiometric accuracies of the systems are sufficient.

By utilizing the red or near infrared spectral regions, we can minimize the contributions to the observed signal from the light reflected upward by the blue or green ocean water and from the blue skylight returned from the ocean surface by Fresnel reflection. The reflectance of whitecaps and foam in this spectral region remains high. Thus, the effective reflectance of a large resolution element on the ocean surface that includes a mix of areas of essentially black water and whitecaps or foam will depend to a first approximation on the relative fraction of the two which are present in the total area. Unfortunately, this situation is complicated by the fact that in the "black" areas the Fresnel reflectance of the surface will return a portion of the light incident from white clouds and the "white" areas actually will have reflectance varying from a high of 80-90% for new whitecaps to a low of perhaps 10% for the streaks prevalent at the higher wind speeds. It is the effective reflectance and its relationship to the wind speed that is the key to determining wind speed by this remote sensing technique. The full nature of this relationship is the information we are seeking in the present study.

From a knowledge of the local meteorology (i.e., cloud cover) and the solar elevation at the time of observation, the irradiance incident on the ocean surface may be determined with reasonable accuracy. If the sky is clear, the incident irradiance together with the effective reflectance of the resolution element is sufficient to determine the inherent radiance of the surface as viewed from above. If however, the sky contains some clouds (i.e., broken) and the ocean surface is viewed through (large) holes in the clouds, it is necessary to generate an estimate of the distribution of radiance above the reflecting resolution element and to convolve this sky radiance distribution with the angular reflectance functions of both the white and the non-white water area. The angular reflectance properties of the white foam should approximate those of a matte or lambertian surface where-as the wind roughened non-white areas will have reflectance properties determined by the statistical nature of the wave slopes.

A remote sensor would measure the apparent radiance of the surface. This differs from the inherent radiance just discussed by the spacelight and transmission properties of the intervening path of sight. These optical properties of the air column seem to be sufficiently well coupled to the meteorological properties that a statement of the meteorological regime extant at the time of measurement of the apparent radiance will allow the inherent radiance to be determined. The correlation of optical and meteorological properties of the air mass has been a matter of interest to the Visibility Laboratory for many years and recently the subject of studies specifically directed toward aiding the solution of remote sensing problems.[1-3]

It may be noted also that the use of the red or near infrared spectral regions as opposed to the blue or green regions results in a significant reduction in molecular scattering effects in the air column (both spacelight and transmission loss).

Thus we see that the proposed technique allows us to determine ocean surface wind speed from a measurement of apparent radiance providing information is available regarding the local meteorology, the solar elevation and the relationship between effective reflectance of the ocean surface and wind speed.

PROCEDURE FOR WHITECAP COVERAGE DETERMINATION

The concept of using photography to obtain a relationship between wind speed and the fraction of the surface covered by white water is certainly not new. This program, however, has afforded an unusual opportunity to obtain high quality, documented, vertical photography of the ocean surface. The main additional difference between this study and most others is that the analysis of the photography is performed instrumentally, thereby removing the subjective judgement of where the edge of the whitecap lies.

The technique consists of obtaining low altitude aerial photography of the ocean in the vicinity of ocean towers or ships that can provide wind field data by measurement as opposed to estimation. In addition to that of the ocean surface, photography is also obtained of a gray scale on the ground (see Fig. 1) to provide a calibration for the overall photographic process. Photographic exposures and film processing are carefully controlled to obtain an adequate dynamic range on the film and to assure that the white water areas do not saturate the film. Sensitometric step tablets are printed at the beginning and end of each roll of film to establish the film characteristic and to assist in estimating the uniformity of processing.

The resulting photography is visually screened for exposure, presence of clouds, glitter, processing defects, and for the frame documentation which allows the identification of time, altitude, etc. Selected frames of the most suitable and best quality photography are then scanned in a high speed scanning microdensitometer (Fig. 2). This instrument, an Optronics International Photoscan System P-1000, is directly interfaced with and controlled by an IBM 360/44 computer (Fig. 3). It was especially constructed to accommodate the large format (9-1/2 inch) aerial film acquired with the RC-8 metric cameras It has scanning apertures of 50, 100, and 200 microns which correspond to ocean surface resolutions of 150, 300, and 600 millimeters at scaling factors of 3000:1. The KA-62 multispectral cameras with 3 inch focal length lenses provide this scale at 750 feet altitude. In the RC-8 cameras with 6 inch focal length, this scale obtains at 1,500 feet. Although the resolution required for remote sensing sea surface wind speeds is of the order of kilometers, resolutions of fractions of a meter allow the examination of the detailed nature of the reflectance function and the separation of some of the experimental artifacts from the desired information.

The scanning speed of the densitometer is such that to build a histogram of the densities of the 1.2 million, 200 micron square picture elements in a 200 by 240 mm field of view takes just over five minutes. Scans at 100 or at 50 microns can be performed at the cost of correspondingly increased scanning times when greater spatial resolution is required. Immediate printouts of tables and plots are obtained of the histogram of picture element densities and the integral of this, the cumulative area in the picture versus photographic density. By scanning the sensitometric step tablets printed on each roll of film and the photographs of the gray scales, film and overall photographic system characteristic curves may be generated from which film densities can be related back to exposure and to the reflectance of the ocean surface (Fig. 4).

RESULTS AND DISCUSSION

Some preliminary results were obtained by scanning some selected Mission 88 photography. Figure 5 is a photograph taken over the North Sea on 14 March 1969 at an altitude of 1,500 feet. The surface wind speeds were 48-50 knots. The large area "A" outlined in white containing most of the frame is approximately 600 meters wide. The large whitecap included within the outline "D" is about the size of a football field (90 m). The four outlined areas were separately scanned and the curves in Figure 6 show cumulative areas having densities equal to or less than the values on the abscissa. Curve A shows the cumulative area-density function for essentially the entire frame; curve B for the small area containing streaks and small whitecaps; curve C for the area having only streaks and background and curve D for the area containing the large whitecap.

The subjective approach for determining a single number for the fraction of the surface covered by white water requires a judgement of where the line separating black and white should be placed. One can appreciate the problems of doing this in photographs such as Figure 5. How, for example, does one properly account for the streaks when using a subjective outlining method? Curve C in Figure 6 shows that in such an area (with the 200 micron aperture used in obtaining the data for these curves) there is essentially no white (low density) area but that the relative amount of the scanned area having densities around 1.0 (10% film transmission) exceeded that of both areas A or B. Thus, the regions containing the streaks are shown instrumentally to have relatively larger amounts of area with intermediate reflectance than the other regions. This is, of course, the result one would anticipate; but we now have the capability of quantitatively describing the observation.

In Figure 7 we see the results of scanning two additional frames taken approximately 10 seconds before and 10 seconds after the previous frame. The spread in the curves is an indication of the variability in the amount of white water present at a given wind speed and shows the necessity of scanning enough frames to obtain a statistically significant functional relationship.

The curves of Figures 6 and 7 show area-film density relationships as opposed to the desired area-surface reflectance functional relationships. The translation from density to reflectance requires both film characteristic and gray scale calibrations. The Mission 88 films did have step tablets printed on them so that film characteristics could be obtained. However, no gray scale photography was obtained so it is not possible to assign reflectance values to the film densities with the required accuracy. In addition, the film was processed in such a way that the useful dynamic range of exposures was only about 10 to 1 instead of the 100 to 1 or greater which can readily be obtained. Thus, the useful information available from these films was restricted to a narrow range of exposures and the likelihood was great that desired scene information would fall on the shoulder or toe of the film characteristic. Nonetheless, a second abscissa has been placed on the top of Figure 7 which shows what the area-reflectance relationship might be if we assume a value of film density for the 100% reflectance point. Such information properly replotted against a rational reflectance scale would represent the type of output one might expect for a single wind speed.

CONCLUSIONS

In summary, an attempt is being made to obtain quantitative relationships between the effective optical reflectance of the ocean surface and surface wind speeds. Documented photography is being obtained and processed for the study by the Earth Resources Aircraft Program. The photography is being machine analyzed to remove the subjectivity which has existed in previous studies and to extract additional information.

A scanning microdensitometer has been obtained and interfaced directly with an IBM 360/44 computer. Computer programs for the processing of the data have been prepared and are being expanded as the data reduction process proceeds.

Figure 8 presents some results of earlier investigations[1,4] and shows an apparently tidy result. However, more recent similar analyses of this type show appreciably lower white water areas.[5,6] Our very preliminary results would appear to be able to embrace both results depending on the white-black demarcation criterion used but generally favor the lower values. We would propose that instead of a single curve it is more completely descriptive of the physical situation to use a family of curves or a surface to describe the wind speed-area-reflectance relationship.

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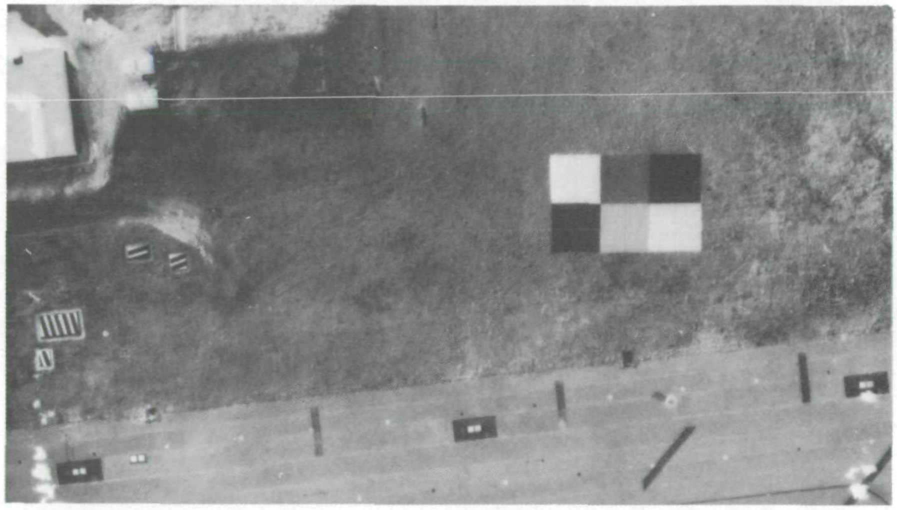

Figure 1. - Canvas Gray Scale deployed next to runway. 20 foot square panels have nominal reflectances of 3, 7, 14, 29, 64, and 83 per cent.

Figure 2. - Scanning Microdensitometer, Optronics International Photoscan System P-1000.

Figure 3. - Visibility Laboratory Interactive Image Manipulation Computer Facility. IBM 360/44 in left background. Interactive input-output console in right foreground.

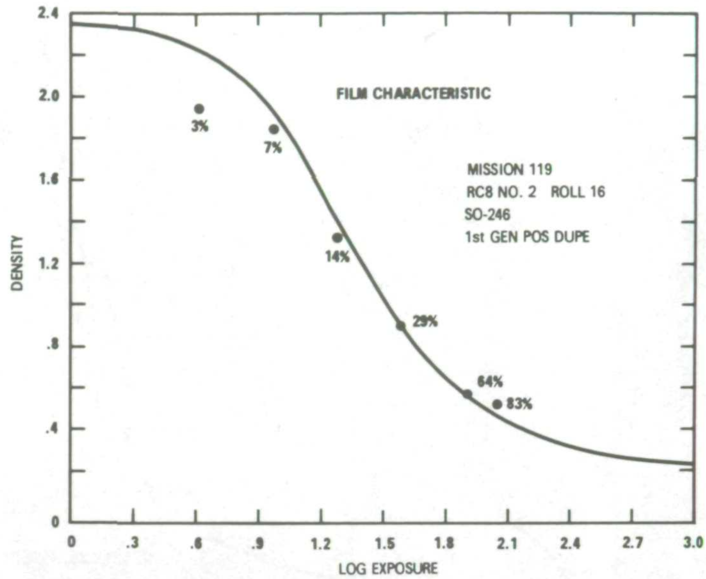

Figure 4. - Typical film characteristic curve with gray scale data superimposed.

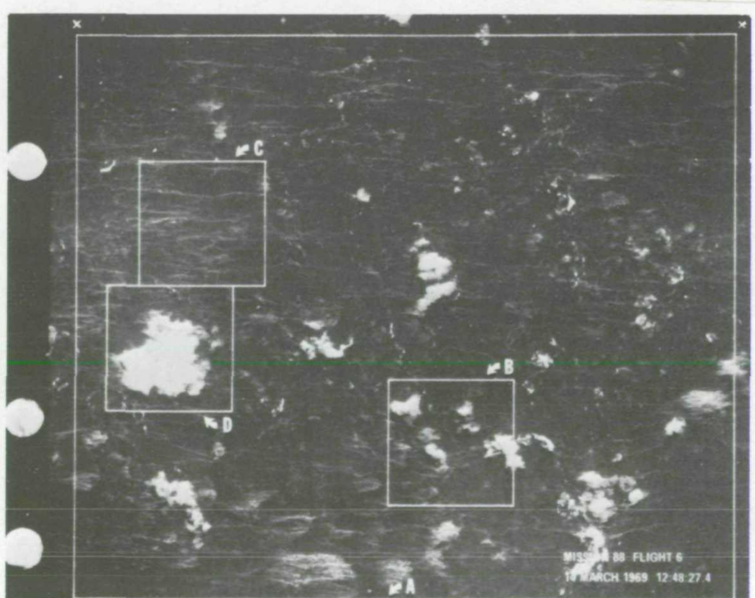

Figure 5. - Frame taken by RC-8 camera on Mission 88 Flight 6 on 14 March 1969 at an altitude of 1500 feet with surface winds of 48 to 50 knots. Large rectangle "A" represents a 500 by 600 meter area on ocean surface. Small squares 110 meters on side show "B" small whitecaps and streaks, "C" streaks only, and "D" large whitecap.

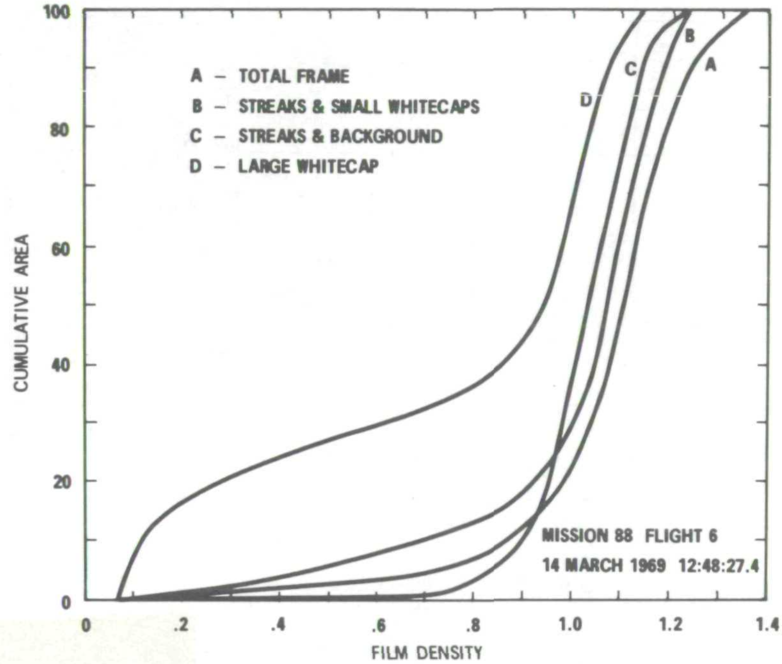

Figure 6. - Cumulative areas (as per cent of total area scanned) versus film density for the four regions outlined in Figure 5.

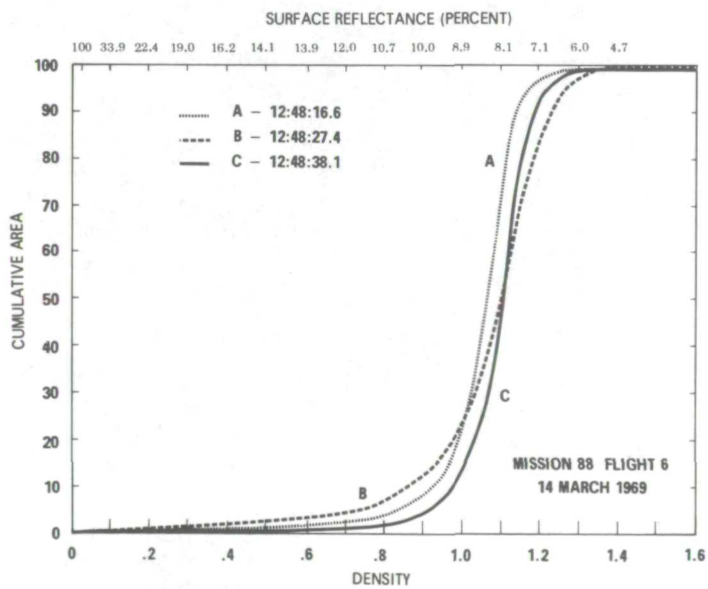

Figure 7. - Cumulative areas for 3 frames of photography taken about 10 seconds apart (no overlap) showing variation occurring in independent areas in the same wind field.

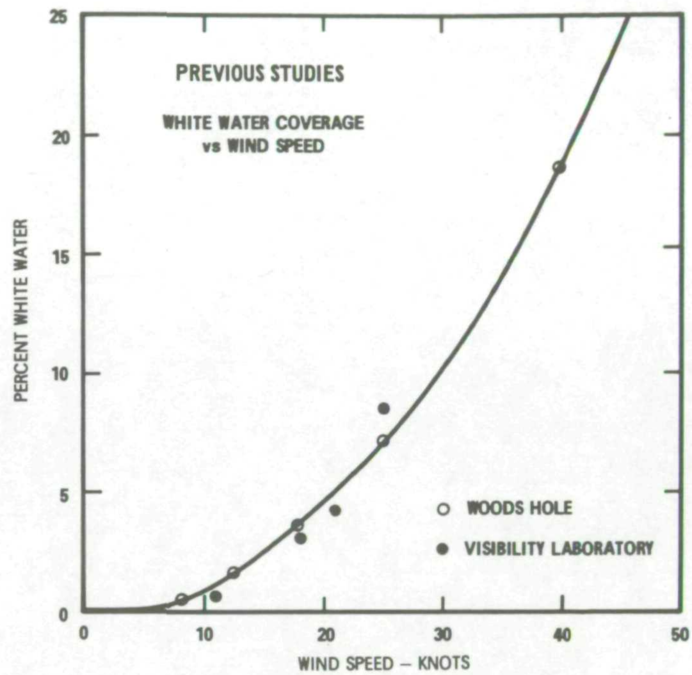

Figure 8. - White water coverage versus wind speed as obtained from earlier studies by Blanchard[4] (Wood Hole) and by the Visibility Laboratory[1]. Present preliminary results are generally lower than those shown in this figure.